State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Northern District

VEGETATIVE RESPONSE TO GEOTHERMAL DRIFT AT THE BOTTLE ROCK GEOTHERMAL POWER PLANT 1984-1992

Technical Information Record
May 1993

SUMMARY

During the initial 1985 power plant startup, the prototype steam scrubbing system failed. This failure resulted in little or no removal of particulates for a period of several months until the scrubbing system was repaired. Visible, heavy salt deposits were apparent within 50 meters (164 feet) of the muffler in the direction of the prevailing wind. Severe vegetative damage and, in some cases, death of mature vegetation directly exposed to geothermal drift from the muffler were obvious within two to three months. Chemical analyses indicated highly elevated (toxic) soil and leaf tissue boron and sodium concentrations. A high disparity between rinsed and unrinsed leaf tissue samples indicated a very high deposition rate. This initial steam scrubber ineffectiveness resulted in severe localized and moderate to light widespread damage.

Between 1985 and 1992, the amount of chemical damage observed during visual assessment of marked plants decreased 71 percent. During this same period, leaf tissue boron concentrations decreased an average of 95 percent and soil boron concentrations decreased 85 percent. Visual assessment of marked plants revealed decreases in chemical, insect, and fungal damage of 63, 47, and 66 percent, respectively over a 20 month period after power plant shutdown in 1990.

Visual assessment of marked plants showed statistically significant differences in the amount of chemical damage when analyzed by direction. The northeast transect (the direction of the prevailing wind) had a significantly greater amount of chemical damage than other transect directions. Chemical damage was also significantly higher within 100 meters (328 feet) of the Bottle Rock Geothermal Power Plant than at distances greater than 200 meters (656 feet). Both results help delineate the areal extent of chemical damage.

Significantly less insect damage was recorded within 50 meters (164 feet) of the power plant pad than at greater distances. The east transect contained significantly greater insect damage than other transects. The east transect is largely protected from geothermal drift by the power plant cut-bank. These results suggest that power plant emissions of boric acid (an insecticide) may be inhibiting insect damage. However, insect damage was not lower in the direction of the prevailing wind, nor has it increased with suspension of geothermal emissions.

Approximately 54 percent of the fungal damage occurred within 50 meters (164 feet) of the power plant. Distances greater than 50 meters (164 feet) each averaged less than 10 percent of the fungal damage. This substantial difference is not statistically significant.

Soil boron levels remain 2.2 times greater than the toxic threshold of 10 ppm within 50 meters (164 feet) of the muffler. Leaf tissue analyses from the same area indicate boron concentrations are less than toxic levels (200 ppm).

The amount of vegetative damage, leaf tissue boron concentrations, and soil boron concentrations showed a downward trend during power plant operations following the initial steam scrubbing system failure. The amount

of chemical damage has decreased rapidly following suspension of power plant operations and is currently approaching baseline levels.

INTRODUCTION

The Department of Water Resources is required by the California Energy Commission and Lake County to monitor and report impacts to native vegetation from cooling tower drift (DWR 1979) and steam field development and operation (Lake County Planning Department 1988). Vegetative damage and associated loss of wildlife habitat productivity were identified in the Bottle Rock Geothermal Power Plant Application for Certification (DWR 1979) as anticipated adverse effects associated with geothermal development on the Francisco Leasehold.

The Bottle Rock Geothermal Power Plant became operational during February 1985. The original steam scrubbing system failed, resulting in particulate deposition on the turbine. Redesign of the steam scrubbing system, cleaning of the turbine, and other technical problems forced the Department to "shut-down" the power plant and stack (vent) steam for extended periods during the spring and summer of 1985.

During the period after steam stacking began, salt deposition was apparent within 50 meters (164 feet) of the muffler in the direction of the prevailing wind (northeast). Department staff first observed visible vegetation damage during this period. Within 60 days, severe vegetative damage was obvious on many overstory species. Several Douglas fir (*Pseudotsuga menziesii*) trees within 50 meters (164 feet) of the muffler sustained the greatest amount of damage and have subsequently died. Although severe damage was apparent on a few individuals, the extent of the damage was quite localized.

The Department "shut-down" the Bottle Rock Geothermal Power Plant on September 16, 1990, due to an inadequate steam supply. No steam stacking has occurred since December 17, 1990.

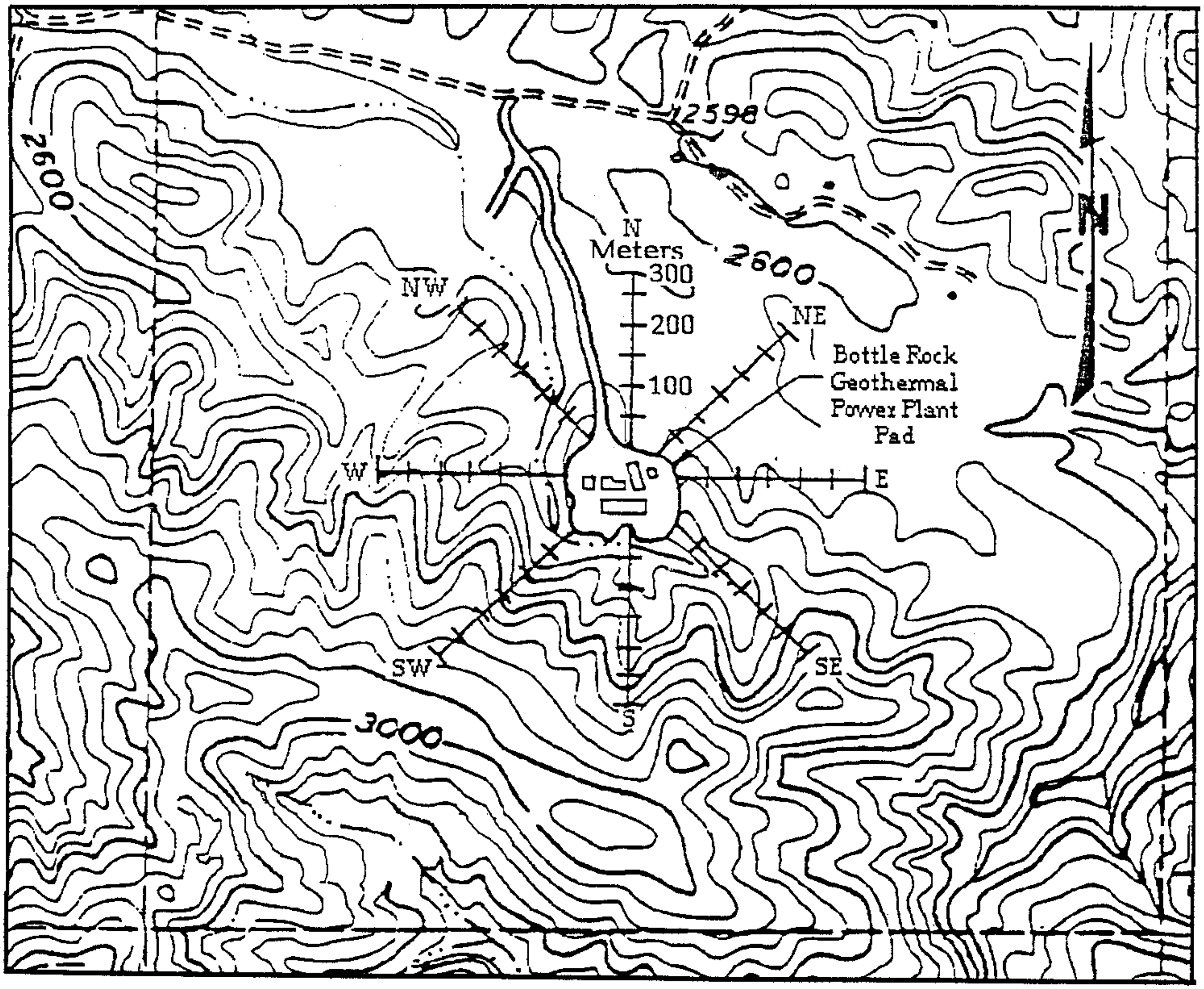
The Department designed a monitoring program to identify where damage occurred, categorize the type of damage by distance and direction, and identify changes in soil and vegetative chemical composition. This information is documented in this report which covers one period from August 1984 through September 1992.

METHODS

Visual Examination of Marked Plants—We established eight transects in 1984 for the purpose of visual analyses of marked plants (Figure 1). At the request of the CEC, transects were established in meters to be comparable to ongoing Pacific Gas and Electric (PG&E) studies. Groups of healthy plants with no visible leaf surface damage were located approximately 50, 100, 150, 200, 250, and 300 meters (164, 328, 492, 656, 820, and 984 feet) from the cooling tower on each transect. Approximately 190 individual plants of 21 species were marked for damage assessment. Photographs were taken of each marked plant for comparative purposes. Each marked plant was examined during August of each year.

The Barratt-Horsfall rating system was applied to a subsample of the leaves of each marked plant to determine the

Figure 1. Vegetative transects around the Bottle Rock Geothermal Power Plant.



Scale 1 inch = 260 meters (853 feet)
Contour Interval = 15.2 meters (50 feet)

Township 12N Range 8W Section 5

amount of leaf surface area damage. The Barratt-Horsfall rating system is based on the fact that an observer's ability to estimate the amount of leaf surface area damage is most accurate near 0 or 100 percent, and least accurate near 50 percent (Barratt and Horsfall 1945).

A representative subsample (20 leaves or needles) was collected from each marked plant and keyed into one of the following percent damage classes: 0, 0-3, 3-6, 6-12, 12-25, 25-50, 50-75, 75-88, 88-94, 94-97, 97-100, and 100.

If any loss of leaf surface area was present, the observed damage was further identified into one of four categories (insect, fungal, chemical, or other) for each marked plant. The "other"category includes leaf surface area damage resulting from various causes including browsing, frost, mechanical breakage, and ecological succession. Leaf surface area damage was analyzed by distance and direction from the cooling towers, since leaf surface area damage resulting from power plant emissions should decrease with increasing distance from the power plant and be greatest in the direction of the prevailing wind.

Aerial False Color Infra-red Photography—Aerial false color infra-red photographs of the leasehold area have been taken by Northern District personnel each August from 1984 through 1991. The aerial false color infra-red photographs can only reveal changes in overstory vegetation. Damage observed to overstory vegetation on the aerial false color infra-red photographs of August 1984 through 1991 were generally also visible to the naked eye. The value of using aerial false color infra-red photographs to detect vegetative damage on the relatively small Francisco leasehold is questionable. Therefore, identification and mapping of overstory vegetative damage was accomplished through direct observation in 1992.

Chemical Analyses—Chemical analyses of plant tissue, duff, and soil samples have been conducted annually since 1985. All samples were collected within 50 meters (164 feet) of the muffler in the direction of the prevailing wind and represent the area exhibiting the greatest amount of deposition and vegetative damage.

Samples collected during the initial steam stacking (1985) were analyzed for boron, sodium, potassium, sulphur, calcium, magnesium, copper, iron, manganese, and zinc concentrations. Samples collected included black oak *(Quercus kelloggii)*, Douglas fir, madrone *(Arbutus menziesii)*, grass (numerous introduced perennial species), and duff. One-half of each sample was labeled and submitted to DWR's Bryte Chemical Laboratory for analysis. The other half of each sample was washed with distilled water to remove surface deposition, labeled, and submitted to the laboratory. Subsequent sampling (1986 through 1992) included soils analysis in addition to the previously mentioned samples. However, post-1985 chemical analyses were restricted to boron and sodium.

RESULTS AND DISCUSSION

Visual Examination of Marked Plants—Total leaf surface area damage from all agents (chemical, fungal, insect,

and other) generally showed an increasing trend while the power plant was operational (Figure 2). During 1991, total vegetative damage decreased approximately 21 percent. Total damage increased again during 1992 but remains approximately 10 percent below peak 1990 total damage levels.

Examination of each of the damage categories indicates that the "other" damage category has been the dominant form of damage since 1987 (Figure 3), and currently comprises 77 percent of the total leaf surface area loss. Browsing, mechanical breakage, frost, and plant succession are the primary agents of the "other" damage category. None of these agents are believed to be directly related to the effects of geothermal drift.

Nearly all the marked deerbrush *(Ceanothus integerrimus)* have been lost (i.e., 100 percent leaf surface area damage) since 1984 due to age and overshading. Deerbrush is a successional, fire adapted species. Lack of fire for the last 26 years has virtually eliminated this short-lived species from the study area. The steady loss of marked deerbrush plants comprises most of the increase in the "other" category since 1984.

Chemical Damage—Chemical damage consistent with boron damage (i.e., marginal necrosis, interveinal necrosis, interveinal chlorosis, conifer needle tip burn or banding) and has decreased approximately 71 percent since the initial power plant shutdown and steam stacking incident during 1985 (Figure 3). Since the power plant ceased operation in 1990, the percent loss of leaf surface area from chemical damage has decreased 63 percent to the lowest level since 1984. The amount of chemical damage decreased approximately 5 percent between 1991 and 1992. A single Douglas fir tree located on the northeast transect at 50 meters (164 feet) was killed during the initial steam stacking incident in 1985. Subsequent vegetative damage assessments (1986 through 1992) continue to record this dead tree as 100 percent loss of leaf surface from chemical damage. This single dead fir tree accounted for over 90 percent of the total chemical damage observed during 1992.

The greatest amount of chemical damage has occurred on the northeast transect (Figure 4), which is the direction of the prevailing wind. Approximately 54 percent of the total chemical damage recorded between 1985 and 1992 occurred on the northeast transect. Chemical damage on this transect was statistically significantly higher (at the 95 percent confidence interval) than that in any other direction. These results indicate that the power plant emissions are the principal source of chemical damage. No statistically significant differences in the amount of chemical damage between years was observed.

The amount of chemical damage was significantly greater at 50 and 100 meters (164 and 328 feet) than at 250 and 300 meters (820 and 984 feet) (Figure 5). Chemical damage generally decreased at increasing distances beyond 100 meters. Approximately 76 percent of the total loss of leaf surface area from chemical damage (1985 through 1992) occurred within 100 meters (328 feet) of the power plant.

Figure 2. Total annual loss of leaf surface area.

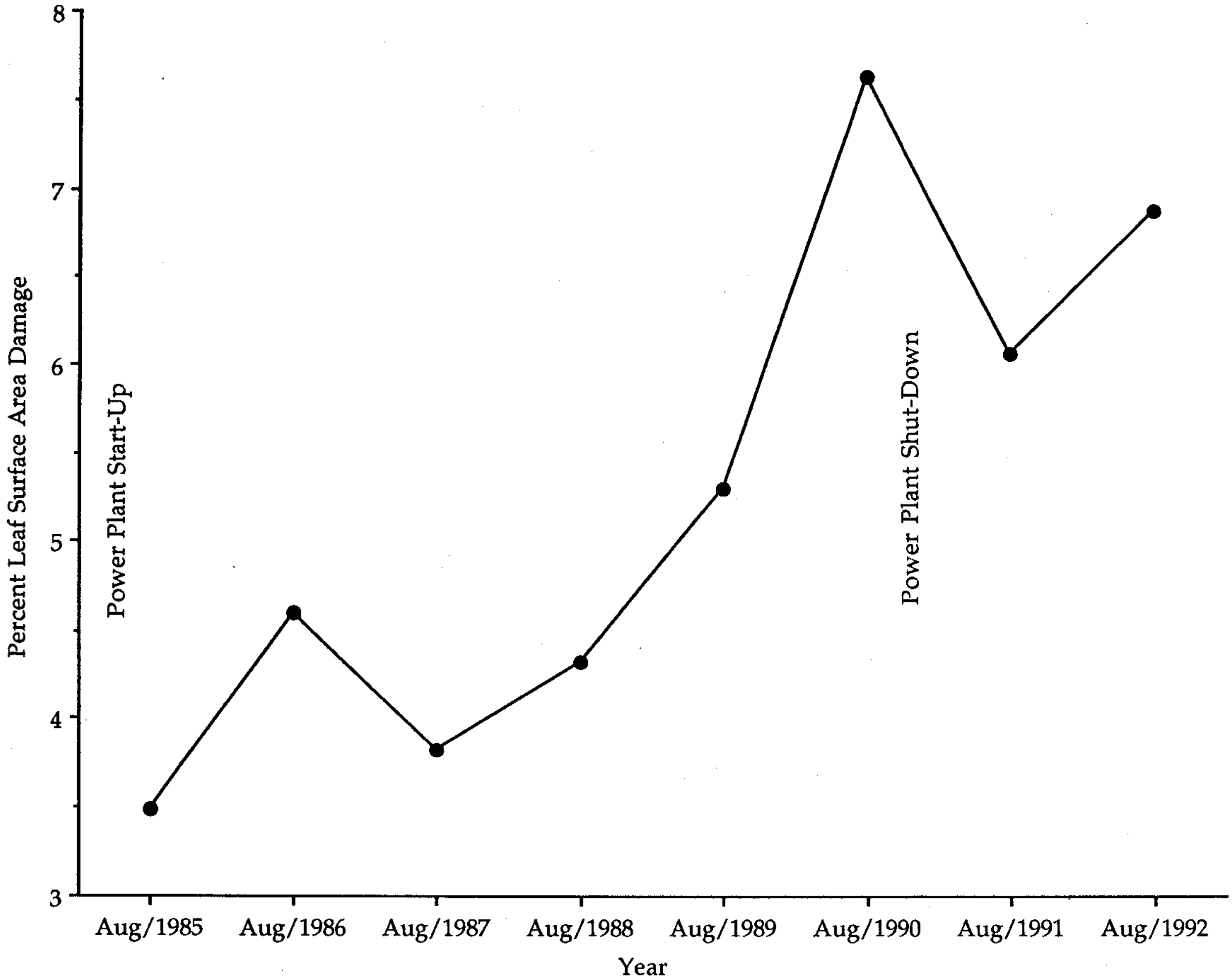


Figure 3. Percent loss of leaf surface area in each damage class.

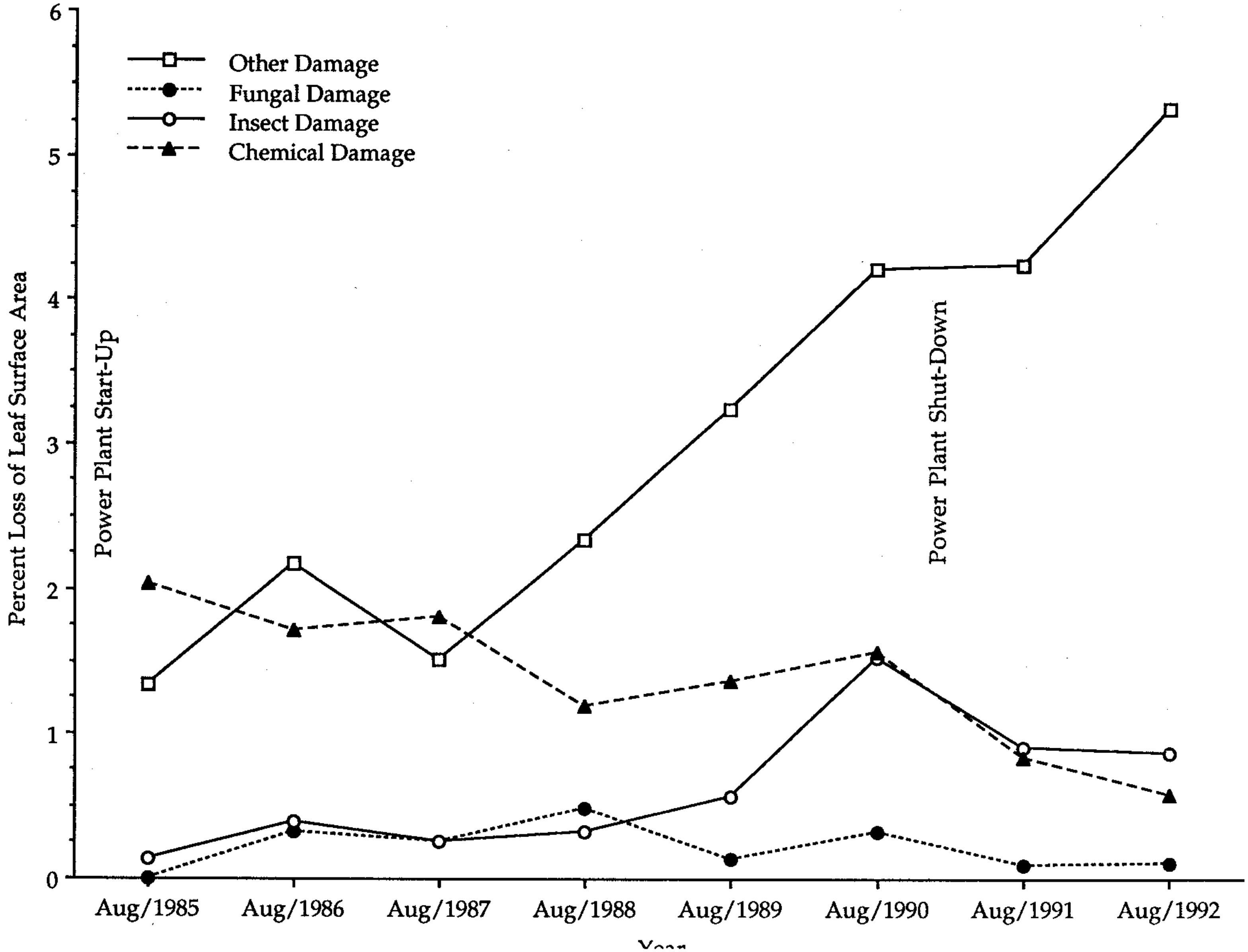


Figure 4. Percent loss of leaf surface area from chemical damage on each transect.

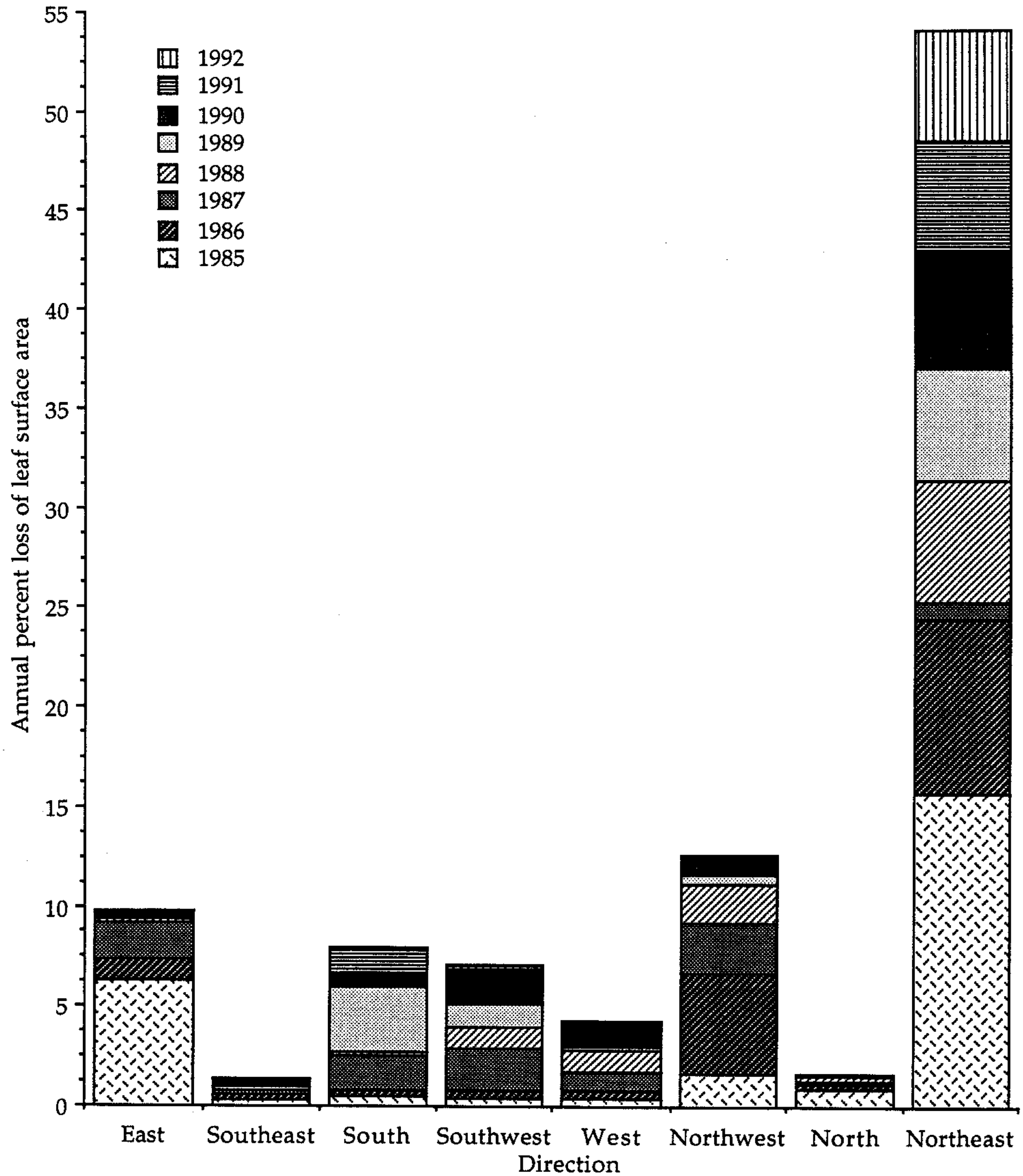
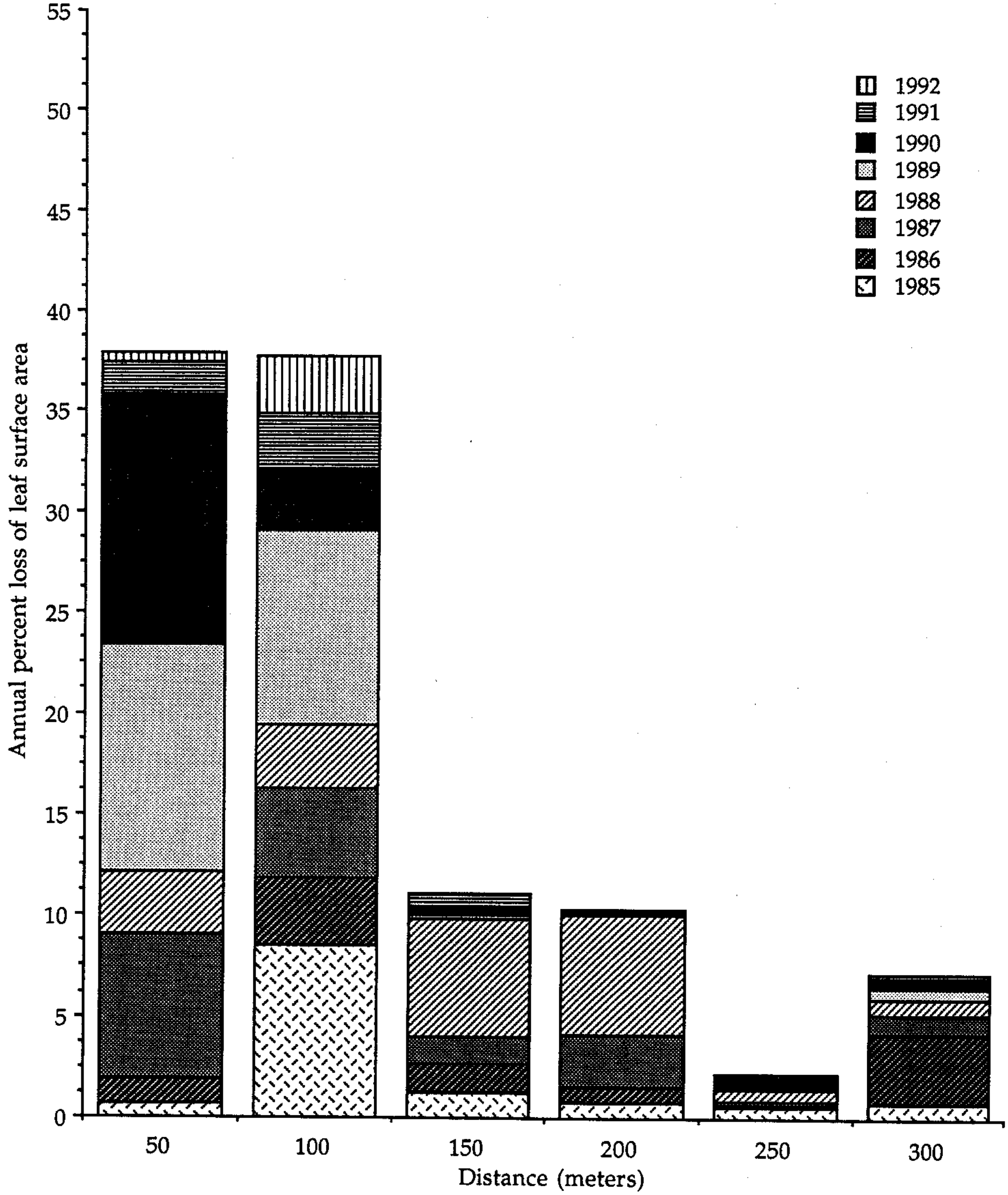


Figure 5. Loss of leaf surface area from chemical damage at each distance.



Insect Damage—The amount of insect damage exhibited an increasing trend between 1984 and 1990 (Figure 3). The loss of leaf surface area to insect damage decreased 42 percent between 1990 and 1991. This decline in the amount of insect damage continued at a slower rate, decreasing approximately 4.5 percent between 1991 and 1992.

Insect damage also appears to vary with direction (Figure 6). Approximately 41 percent of the total insect damage (1985 through 1991) occurred on the east transect. However, only 27 percent of the total insect damage was recorded on the east transect during 1992. This transect is largely protected from geothermal drift by the power plant cutbank. The relatively high amount of insect damage on the east transect was significantly greater than that in any other direction. Total insect damage from all transects was also significantly higher during 1990 than in previous or subsequent years.

Boric acid is commonly used as an insecticide. The high amount of insect damage on the protected east transect relative to other directions could indicate that the boric acid contained in the drift is suppressing insect populations in unprotected areas. However, the amount of insect damage is not statistically lower in the direction of the prevailing wind nor has damage increased with elimination of geothermal emissions. Both these results would be expected if levels of boric acid were present in high enough concentrations to influence insect population levels.

Insect damage was recorded within 50 meters (164 feet) of the power plant only during 1990 (Figure 7). The loss of leaf surface area from insect damage increased sharply from 50 to 150 meters (164 to 492 feet) then decreased with increasing distance. Total loss of leaf surface area at 50 meters (164 feet) was significantly less than at increasing distances. Again, this is consistent with the effects of boric acid as an insecticide.

Fungal Damage—The loss of leaf surface area to fungal damage has remained at relatively low levels since 1985, never accounting for more than 12 percent of the total damage (Figure 3). Since the power plant shutdown in 1990, the amount of leaf surface area loss to fungal damage has decreased approximately 66 percent. A slight increase in the loss of leaf surface area to fungal damage occurred between 1991 and 1992.

Analyses of fungal damage by directions and year indicate relatively low levels of damage with no statistically significant differences between direction or years (Figure 8).

The majority of fungal damage occurred within 50 meters (164 feet) of the power plant (Figure 9). This difference was not statistically significant. Increased relative humidity has been correlated with increased fungal disease on native flora adjacent to geothermal power plants (Espey, Huston, and Associates 1981). These results support that conclusion.

Aerial False Color Infra-red Photography Analysis—The 1984 baseline photographs indicated localized moderate vegetative damage around the Lower Coleman well pad (Figure 10). Three scattered ponderosa pines *(Pinus*

Figure 6. Percent loss of leaf surface area from insect damage on each transect.

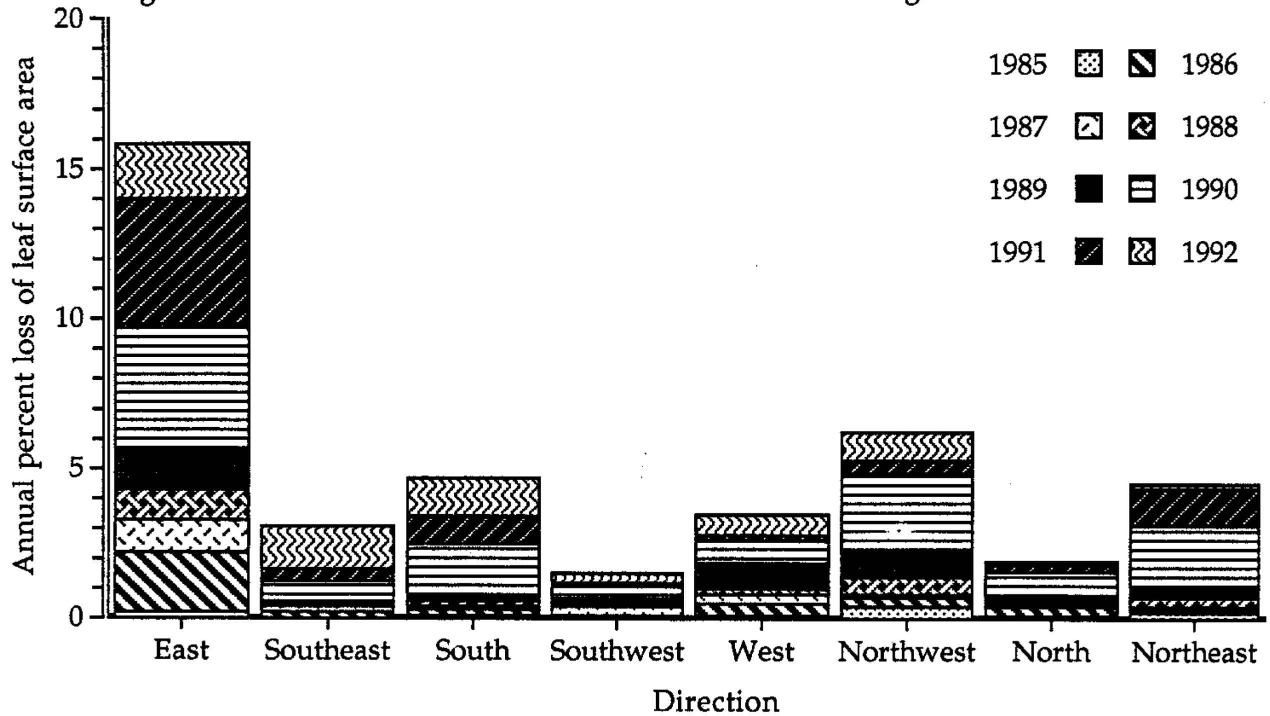


Figure 7. Loss of leaf surface area from insect damage at each distance.

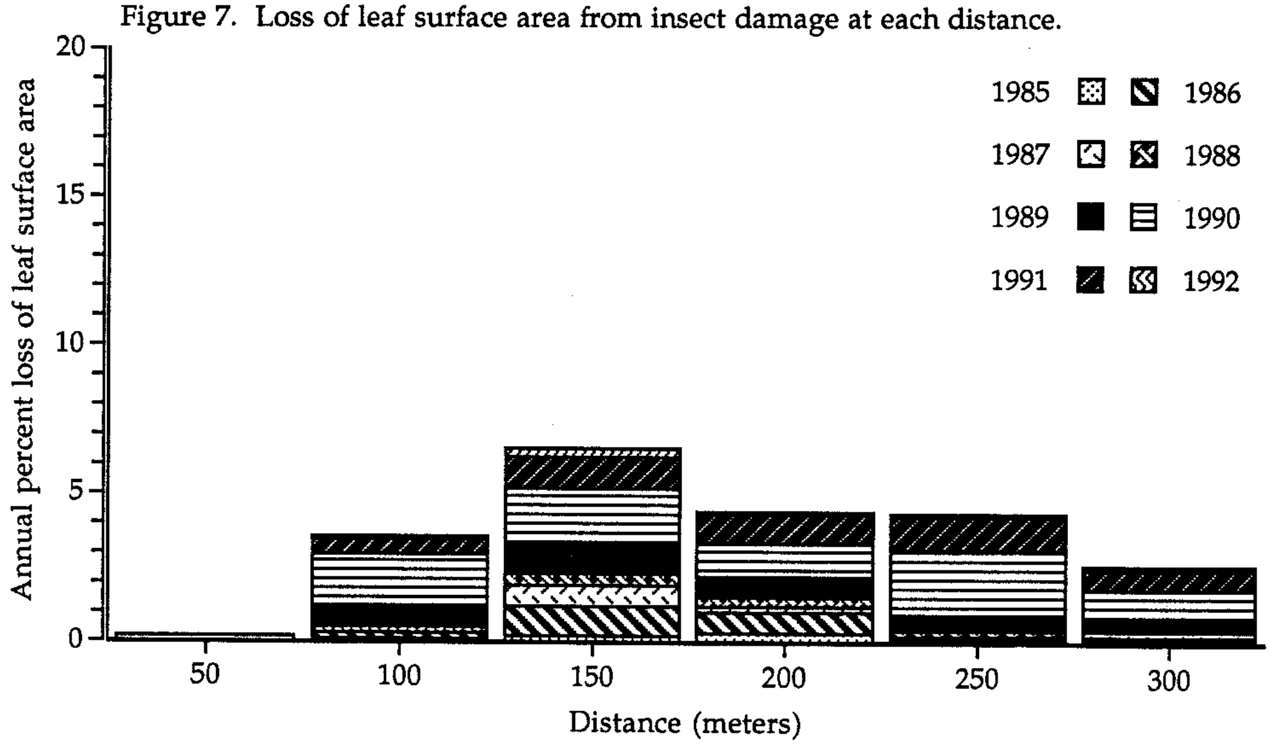


Figure 8. Percent loss of leaf surface area from fungal damage on each transect.

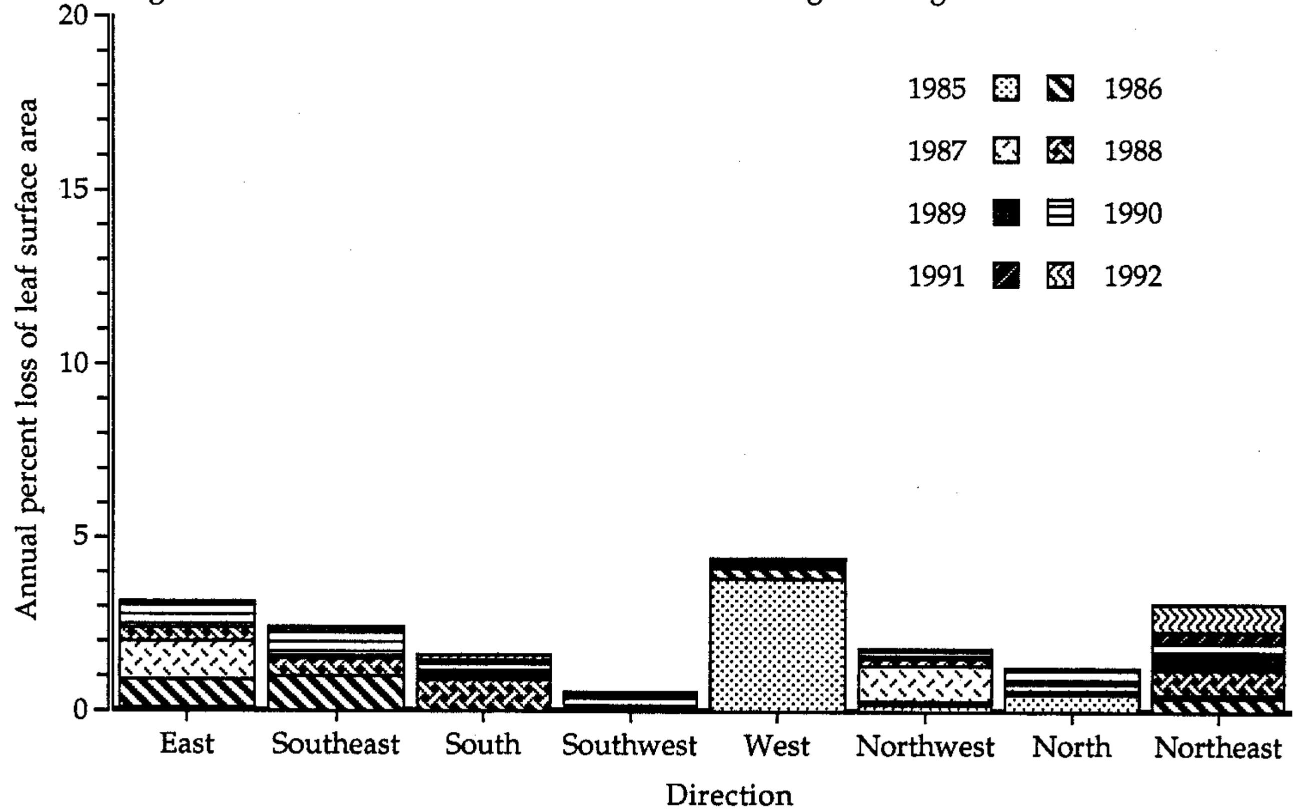


Figure 9. Loss of leaf surface area from fungal damage at each distance.

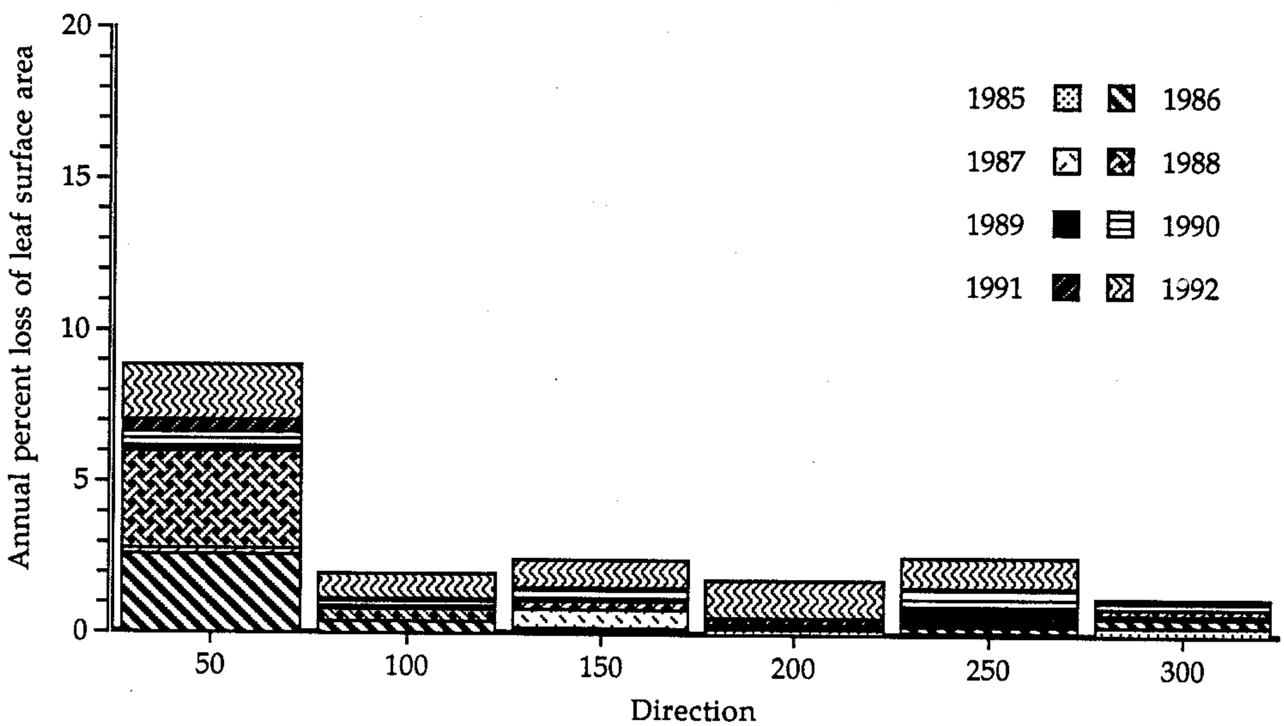
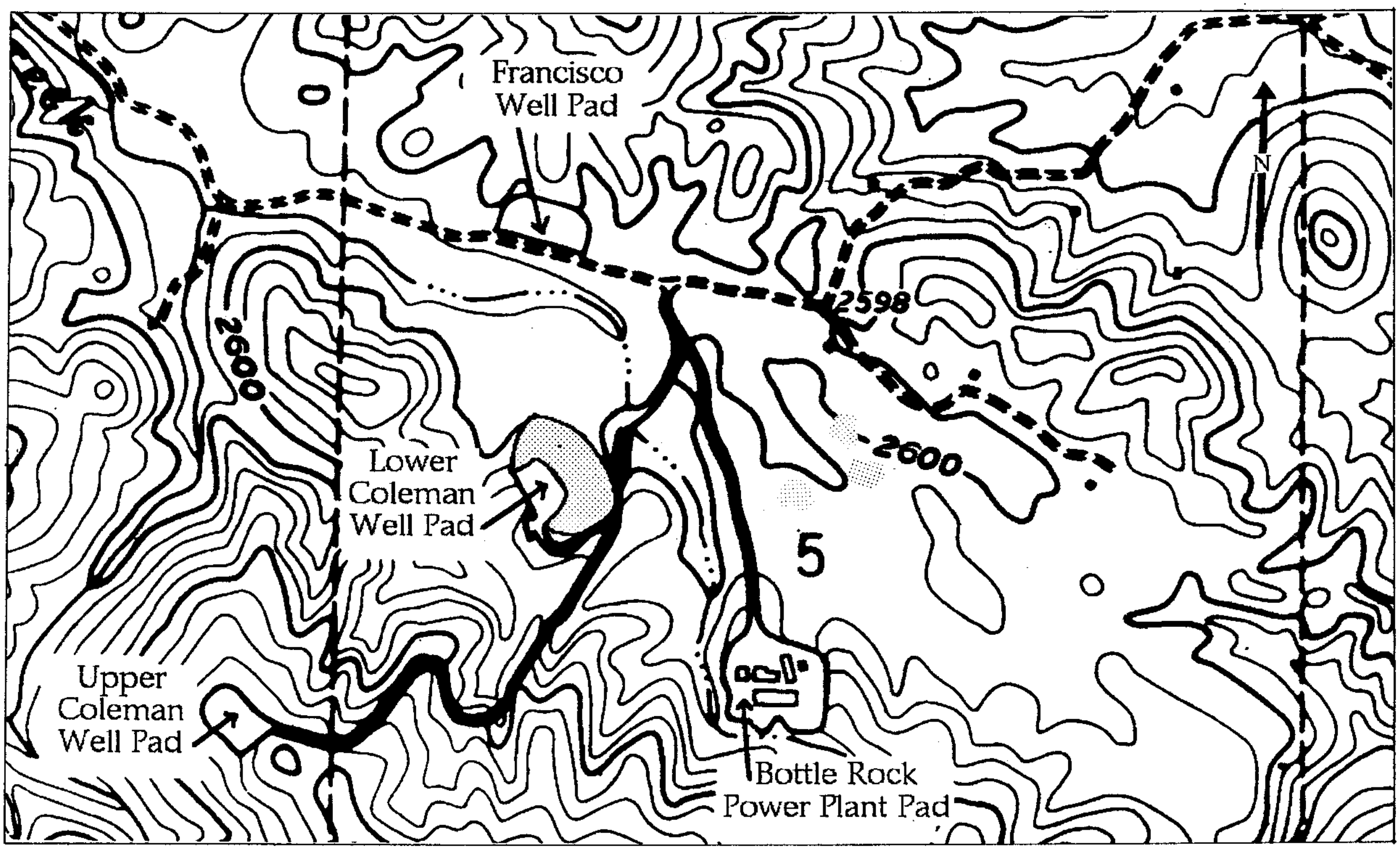


FIGURE 10. Vegetative Damage on the Francisco Leasehold in 1984.



Legend ░ Visible Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 meters (50 feet)

ponderosa) located approximately 350 meters (1,148 feet) north of the power plant also exhibited vegetation stress in 1984.

The 1985 aerial photographs revealed a small area of severe damage adjacent to and northeast of the power plant pad (Figure 11). A relatively large area of visible damage was also identified north of the power plant. Two relatively small areas of visible damage were identified around the Lower Coleman well pad.

Analysis of 1986 photographs indicated an increase in the extent of severe vegetative damage north and northeast of the power plant (Figure 12). The extent of visible damage decreased in the areas north of the power plant, but increased slightly in the northeast. A small area of extensive damage was apparent along the steamline running from the power plant to the Lower Coleman well pad.

The 1987 photographs showed a small area of severe vegetative damage adjacent to the Lower Coleman well pad, and small areas of moderate to severe damage near the northeast and west corners of the power plant pad (Figure 13). Spotty vegetative damage along the unnamed tributary to High Valley Creek, running west and northwest of the power plant, was also noted. A substantial decrease in the extent and severity of damage northeast of the power plant was observed.

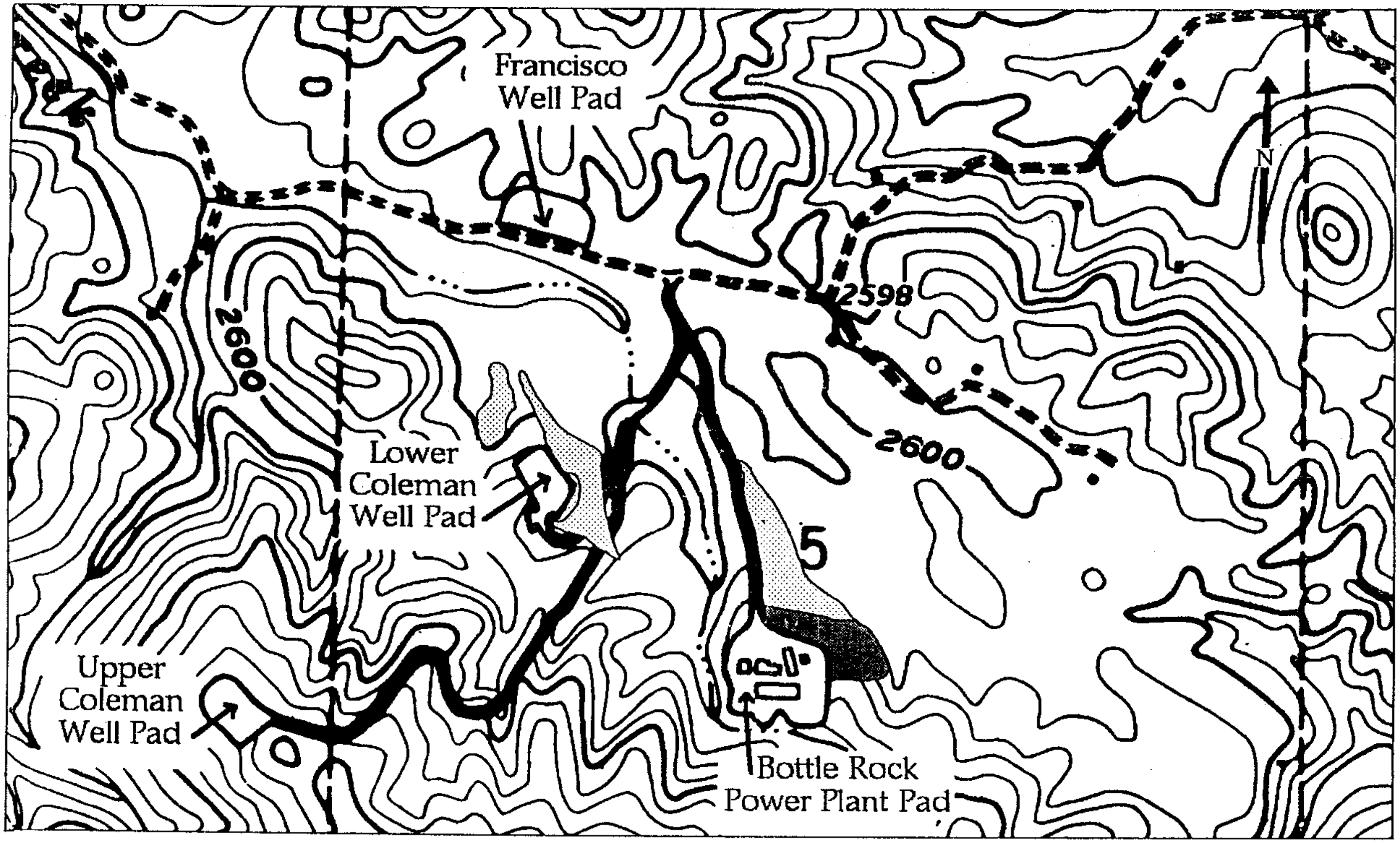
Analysis of 1988 photographs revealed a further decrease in the aerial extent of damage northeast of the power plant pad (Figure 14). A small area of severe vegetative damage east of the Lower Coleman well pad was also apparent. Vegetative damage identified with aerial photography was more restricted and less severe during 1988 than in any previous year.

Analysis of 1989 photographs indicate damage to a small stand (approximately 10 trees) of ponderosa pine located near the Union Road crossing of the unnamed tributary to High Valley Creek (Figure 15), which was the result of western pine bark beetle infestation. A small patch of knobcone pines located approximately 320 meters (1,050 feet) north of the Francisco Well pad died during 1989. Several scattered ponderosa pines near the Lower Coleman well pad also showed signs of moderate to heavy vegetative stress. A large ponderosa pine located approximately 366 meters (1,200 feet) east of the power plant appears heavily stressed due to road fill material surrounding its base. The majority of the vegetative stress is scattered and appears to be related to region-wide drought stresses, rather than effects of geothermal drift. No increased vegetative stress due to synergistic effects of geothermal drift and the drought have been noted.

During 1990 and 1991, several scattered mature ponderosa pine and sugar pine trees succumbed to western pine bark beetle infestations (Figure 16). Vegetative stress that was apparent following the initial steam stacking event has been reduced in scope and severity.

Visual analysis of vegetative damage during 1992 indicated scattered individual conifers in a stressed condition (Figure 17).

Figure 11. Vegetative Damage on the Francisco Leasehold in 1985

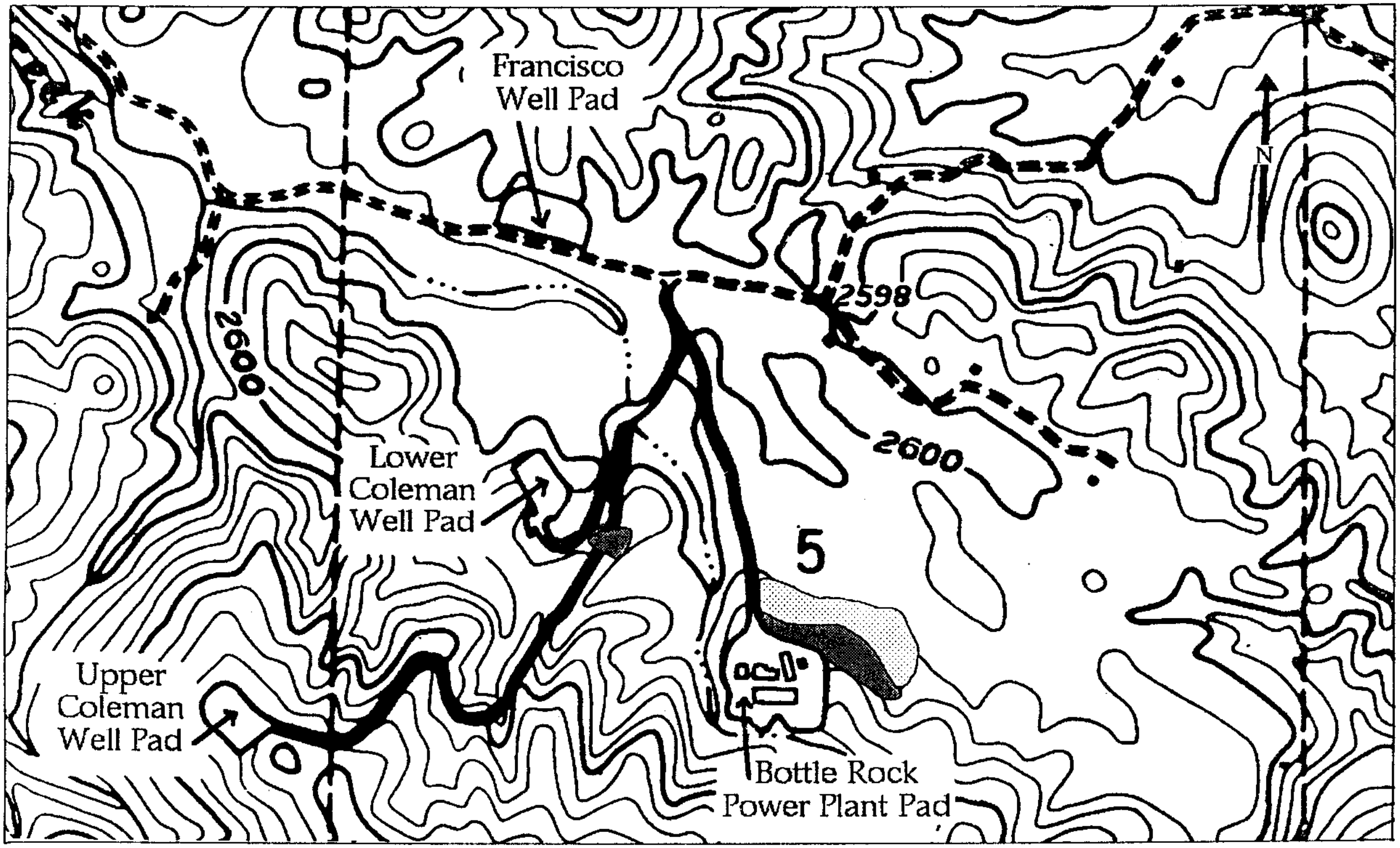


Legend: Visible Vegetative Damage; Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 12. Vegetative Damage on the Francisco Leasehold in 1986.



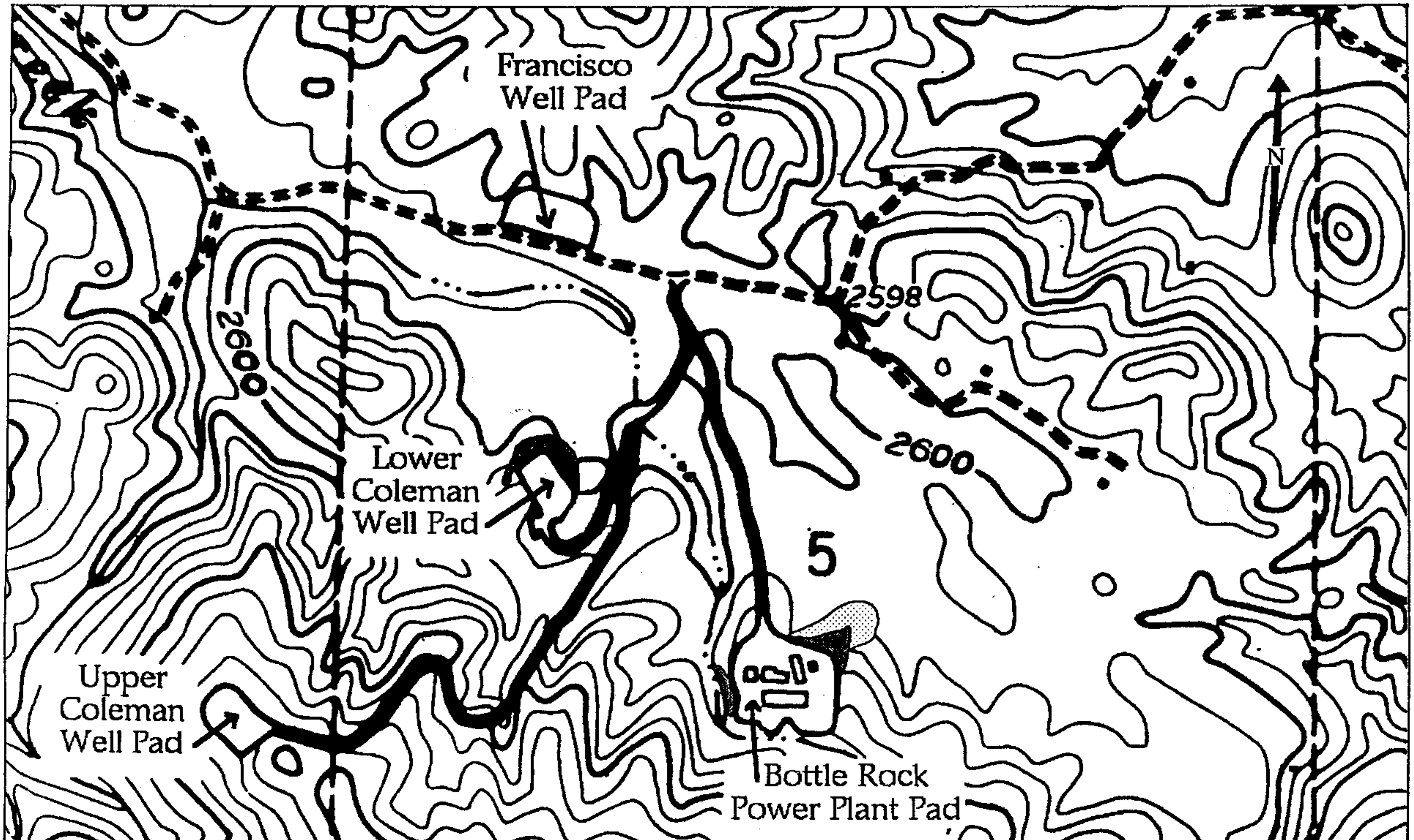
Legend ░ Visible Vegetative Damage

▒ Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 13. Vegetative Damage on the Francisco Leasehold in 1987

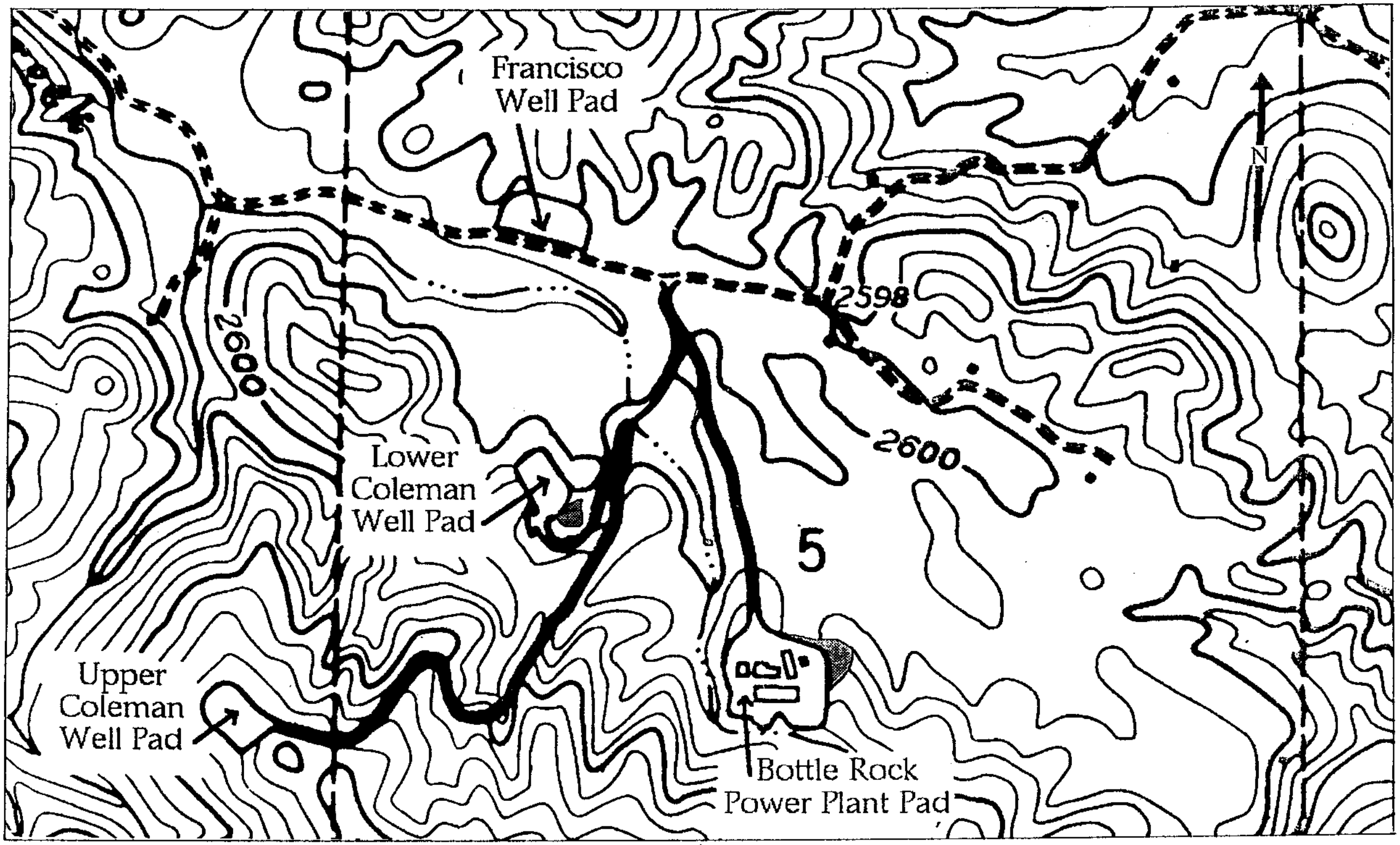


Legend: Visible Vegetative Damage; Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 14. Vegetative Damage on the Francisco Leasehold in 1988

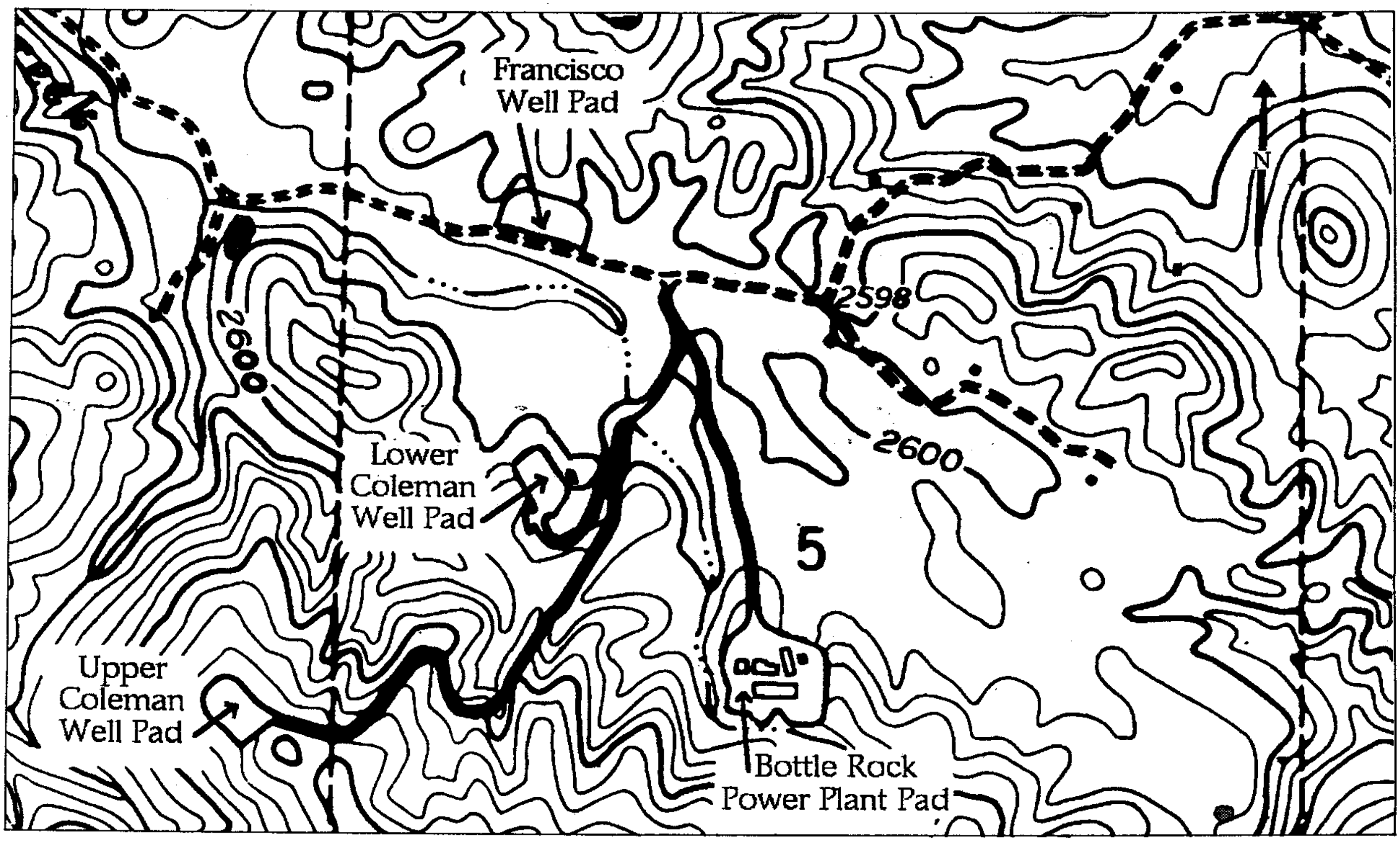


Legend: Visible Vegetative Damage; Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 15. Vegetative Damage on the Francisco Leasehold in 1989

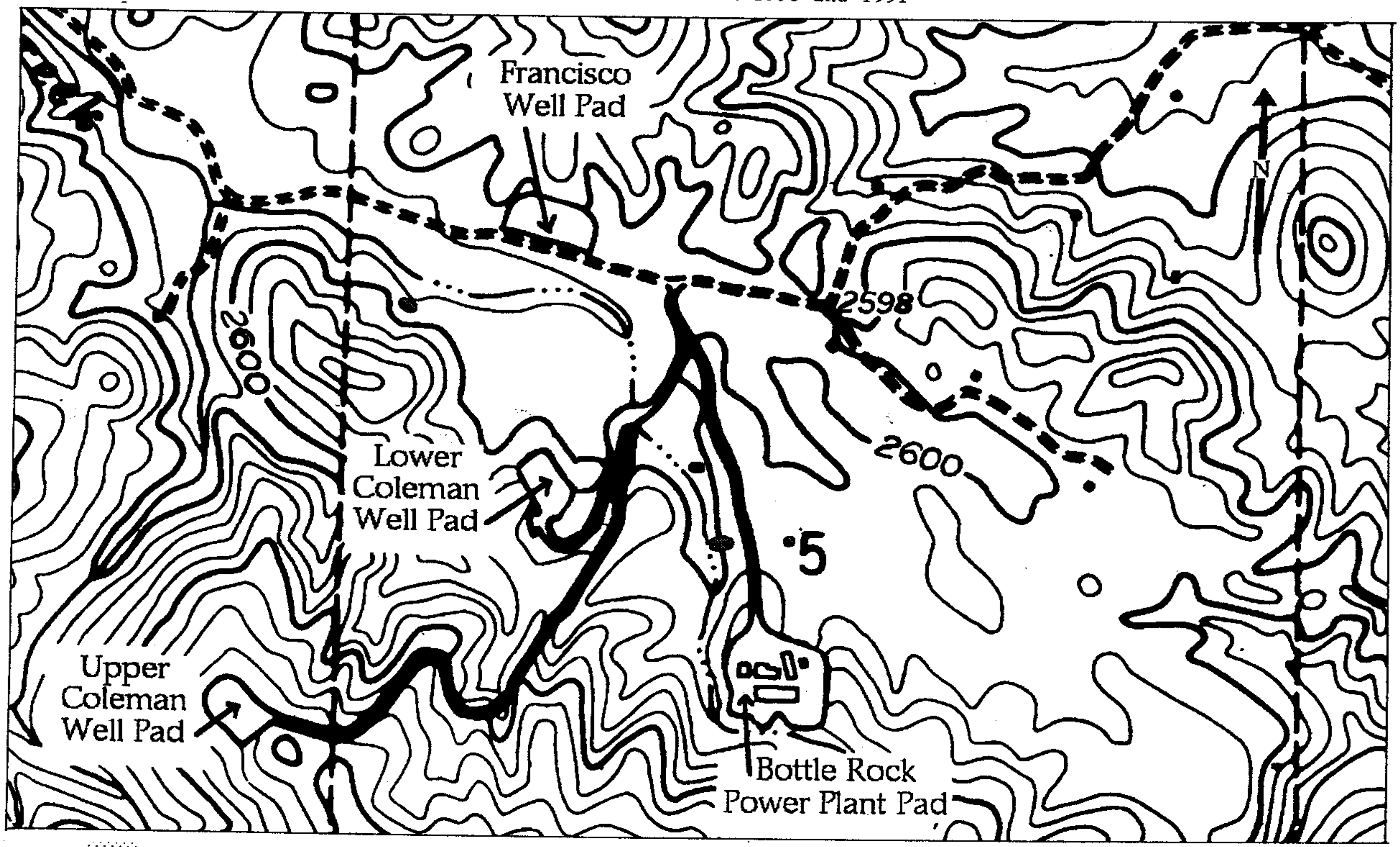


Legend: Visible Vegetative Damage — Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 16. Vegetative Damage on the Francisco Leasehold in 1990 and 1991



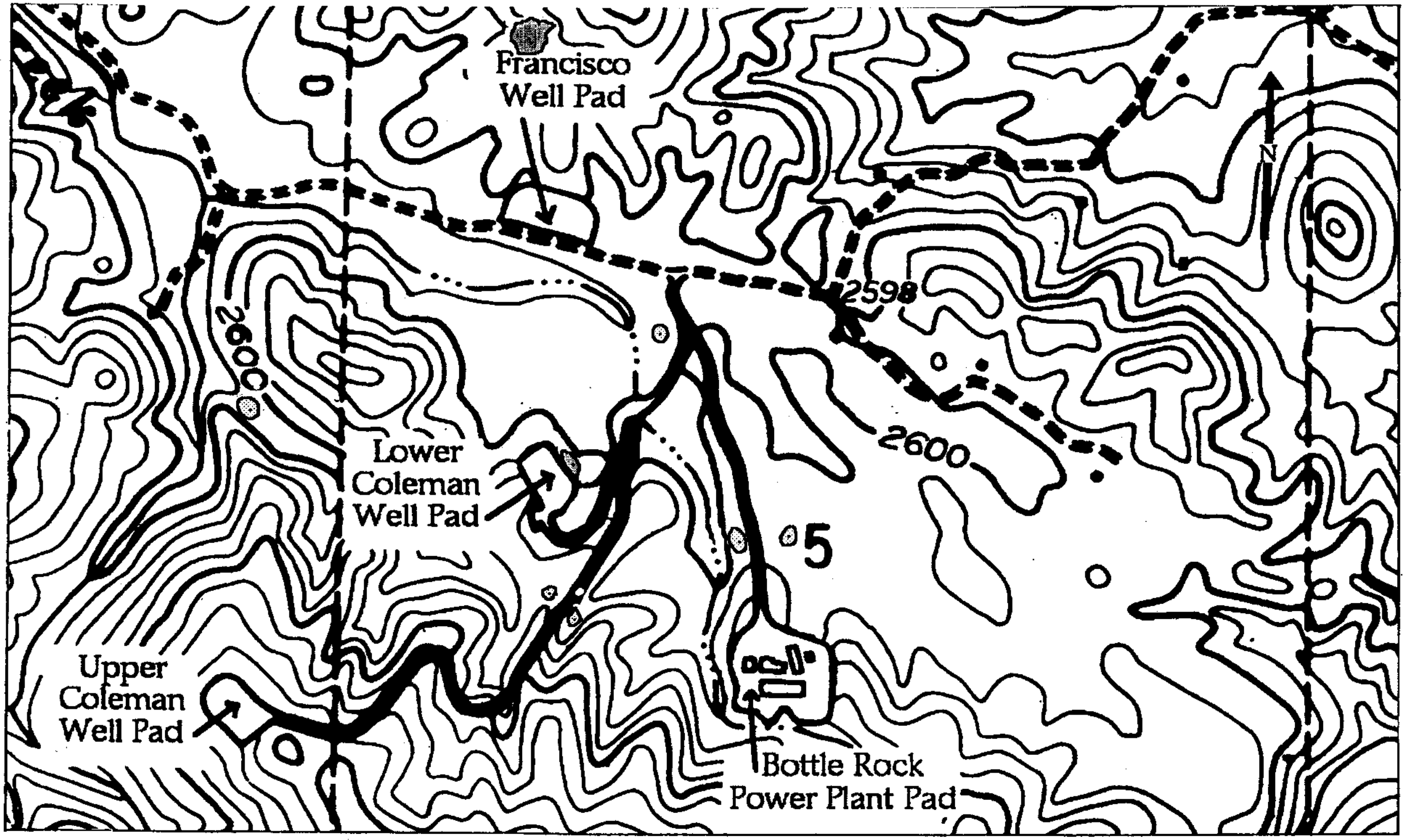
Legend Visible Vegetative Damage

Severe Vegetative Damage

Scale 1 Inch = 250 Meters (820 feet)

Contour Interval 15.2 Meters (50 feet)

Figure 17. Vegetative Damage on the Francisco Leasehold in 1992.



Legend Visible Vegetative Damage Scale 1 Inch = 250 Meters (820 feet)

Severe Vegetative Damage Contour Interval 15.2 Meters (50 feet)

Severe vegetative damage was apparent in a small stand of mature knobcone pines located approximately 350 meters (1,148 feet) north of the Francisco Well Pad. Severe vegetative damage was also observed in a stand of ponderosa pine seedlings located on the northeast facing fill slope of the Coleman Well pad. Visible damage was noted on scattered, mature ponderosa pine, Douglas fir and sugar pine. Little or no damage to mature oaks or other hardwood species was apparent.

Chemical Composition of Soil and Plant Tissue—Composite samples of duff, grass (mixed perennial species), madrone, Douglas fir, and black oak were collected by district personnel during October 1985 from the area within 50 meters (164 feet) of the Bottle Rock Geothermal Power Plant muffler. This area experienced the greatest amount of deposition and vegetative damage during the initial (1985) power plant shutdown. The samples collected represent worst case rather than representative sampling. Subsequent samples have been collected from the same location in the same manner.

The October 1985 rinsed samples contained sodium at concentrations ranging from 13,000 to 20,000 ppm dry weight, while boron concentrations ranged from 600 to 1,300 ppm (Table 1). Tree crops are sensitive to sodium at levels exceeding 5,000 ppm dry weight (Dr. F. Bingham, U.C. Riverside, pers. comm.), while toxic reactions to boron frequently occur at levels exceeding 200 ppm (Bradford 1966). Background levels of boron in plants range between 25 and 150 ppm dry weight. The boron levels observed in rinsed plant tissues collected during October 1985 were approximately three to six times greater than the levels known to be toxic in some species.

Rinsed samples contained from 30 to 72 percent of the boron and from 43 to 87 percent of the sodium contained in unrinsed samples, indicating concentrated deposition on leaf surfaces. In natural situations little or no boron or sodium would be expected on the surface of the leaf.

Duff samples contained the highest concentrations of both sodium and boron. Premature leaf abscission due to boron toxicity probably contributed organic matter with elevated boron concentrations to the duff. Precipitation and deposition undoubtedly also contributed to the high boron levels found in duff samples.

All other constituents were below toxic levels.

Subsequent samples for boron and sodium analyses were collected on November 14, 1986, prior to steam stacking, and December 17, 1986, after 33 days of steam stacking (Tables 2 and 3). All sodium analyses indicated concentrations well below the 5,000 ppm dry weight toxic threshold during this period. Sodium concentrations currently remain well below toxic levels.

Soil boron levels doubled from 70 ppm to 148 ppm following the 33 days of steam stacking. Soil boron concentrations of 10 ppm are considered toxic to even tolerant crops (U.C. Agricultural Extension Service 1969). Samples collected within 50 meters (164 feet) of the muffler during July 1987 and

Table 1. Concentration (ppm) of various elements found from analyses of leaf tissues and duff collected in 1985 near the Bottle Rock Power Plant.

	Black Oak		Madrone		Douglas Fir		Grass		Duff
	Rinsed	Unrinsed	Rinsed	Unrinsed	Rinsed	Unrinsed	Rinsed	Unrinsed	Unrinsed
Boron	1300	1800	600	1100	1000	1800	700	2300	2800
Calcium	5200	8800	3400	5500	5500	5600	1200	1700	1400
Copper	8.8	11.0	26.0	5.6	5.8	8.0	94.0	140.0	7.1
Iron	240	740	120	410	200	1000	130	320	1800
Magnesium	1900	2200	1200	1800	960	1400	890	1200	1400
Manganese	430	560	21	50	120	170	100	250	440
Potassium	3500	6900	4200	5800	4900	5600	3800	10000	3200
Sodium	14000	31000	13000	15000	20000	36000	19000	44000	53000
Sulphur	1900	6600	2900	3500	3800	9100	4300	9000	14000
Zinc	33	32	18	18	20	22	36	42	27

Chemical analyses conducted by Bryte Chemical Laboratory

Table 2. Boron concentrations in leaf tissue and soil samples collected from within 50 meters (164 feet) of the muffler.

Date	Soil Unrinsed	Duff Unrinsed	Grass Rinsed	Grass Unrinsed	Douglas Fir Rinsed	Douglas Fir Unrinsed	Madrone Rinsed	Madrone Unrinsed	Black Oak Rinsed	Black Oak Unrinsed
Oct-85		2800	700	2300	1000	1800	600	1100	1300	1800
Nov-86	70	203	279	476	334	387	296	324	514	463
Dec-86	148	232	130	168	470	373	198	323	423	384
Jul-87	87	96	330	410	180	120	74	93	200	410
Jun-88	69	67	140	240	110	160	67	62	210	180
Oct-88	48	62	73	72	140	130	65	65	160	270
Jun-90	40	70	14	87	26	47	35	54	140	138
Jun-91	25	57	81	97	110	100	62	250	110	100
Jun-92	22	61	52	42	47	40	69	73	86	160

Table 3. Sodium concentrations in leaf tissue and soil samples collected from within 50 meters (164 feet) of the muffler.

Date	Soil Unrinsed	Duff Unrinsed	Grass Rinsed	Grass Unrinsed	Douglas Fir Rinsed	Douglas Fir Unrinsed	Madrone Rinsed	Madrone Unrinsed	Black Oak Rinsed	Black Oak Unrinsed
Oct-85		53000	19000	44000	20000	36000	13000	15000	14000	31000
Nov-86	514	256	2140	3470	1100	366	88	126	302	264
Dec-86	697	140	638	720	638	727	94	98	296	355
Jul-87	750	100	710	630	130	180	42	150	200	290
Jun-88	220	70	420	1400	66	86	54	76	120	180
Oct-88	210	110	110	170	68	230	30	110	180	210
Jun-90	308	102	1980	1320	50	84	44	66	148	134
Jun-91	190	120	430	500	34	44	36	40	22	220
Jun-92	48	150	160	1300	94	180	48	72	70	110

Chemical analyses conducted by Bryte Chemical Laboratory

June 1988 revealed soil boron concentrations over six to eight times the toxic threshold of 10 ppm. Soil boron levels peaked during December 1986 and by June 1992 were only 15 percent of peak levels (Figure 18). Soil boron levels show a declining trend since 1986 as precipitation leaches soluble boron from the soil. Soil boron concentrations remain at over twice toxic levels.

Duff boron levels increased slightly (14 percent) during the same 33 day steam stacking period. Duff boron concentrations were only two percent of peak 1985 levels by June 1992 (Figure 19). Boron is believed to be carried passively from the soil within the vascular system of plants to the leaves. Approximately two-thirds of the boron contained by a plant is present in the leaves (Eaton 1944). As boron accumulates within leaves to toxic levels, premature leaf abscission may occur. The very high 1985 duff boron concentrations probably contained these abscised leaves as well as surface deposition, resulting in higher boron concentrations than those found in unrinsed leaf tissue samples collected the same day. The current (1992) soil boron levels are generally not producing toxic concentrations in leaf tissues or extensive loss of leaf surface area.

All other analyses indicated reduced boron levels in all samples except rinsed Douglas fir following the 33 days of steam stacking. The factors contributing to the general decrease in leaf tissue boron are unknown. Heavy rainfall during the steam stacking period may have rinsed particulates from leaf surfaces into the duff and soil, preventing absorption into and adsorption onto the leaves. All leaf tissue samples were above the potentially toxic level of 200 ppm for boron both before and after steam stacking, except grass and rinsed madrone samples.

Boron concentrations in leaf tissue analyses of perennial grass species are currently 2 and 7 percent of peak levels for unrinsed and rinsed samples, respectively (Figure 20). All grass samples collected since 1988 are below the toxic threshold value of 200 ppm.

Douglas fir leaf tissue boron concentrations are currently 2 and 5 percent of peak levels for unrinsed and rinsed samples, respectively (Figure 21). All Douglas fir leaf tissue samples collected since 1986 remain below toxic levels.

Current madrone leaf tissue analyses indicate that boron levels in rinsed and unrinsed samples are 7 and 11 percent, respectively, of peak 1985 levels (Figure 22). With the exception of the 1991 unrinsed sample (250 mg/kg), all madrone samples collected since 1986 remain below threshold levels.

Black oak leaf tissue boron concentrations are currently 7 and 9 percent of peak 1985 levels for rinsed and unrinsed samples, respectively (Figure 23). Black oak accumulated greater boron levels within leaf tissues than either madrone or Douglas fir on nearly every sampling. The rate of boron accumulation varies from species to species (Eaton 1935), and with season in at least some species (Biggar and Fireman 1960, Gouge and Sanderson 1973).

Figure 18. Soil boron concentrations within 50 meters (164 feet) of the Bottle Rock muffler.

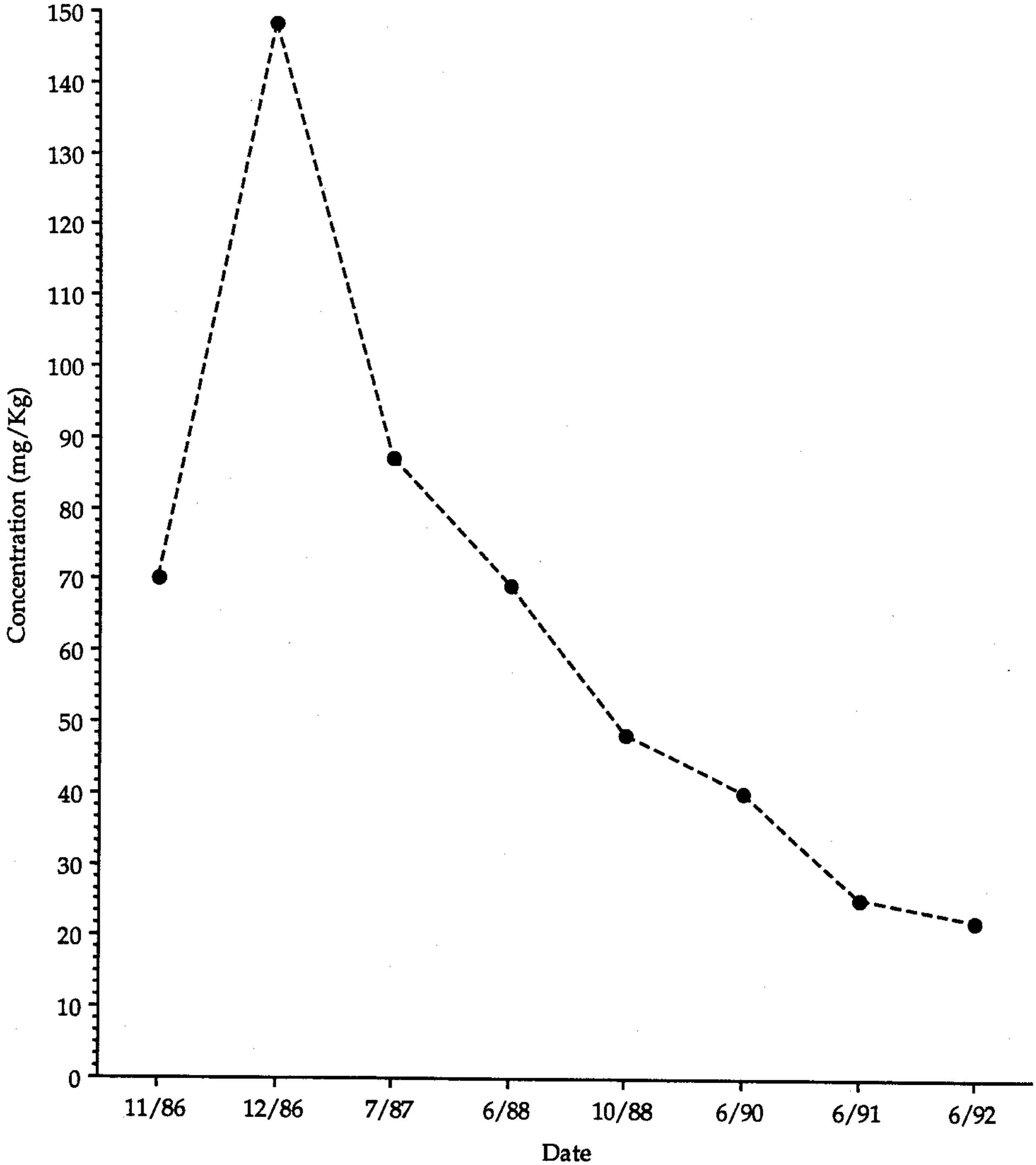


Figure 19. Duff boron concentrations within 50 meters (164 feet) of the Bottle Rock muffler.

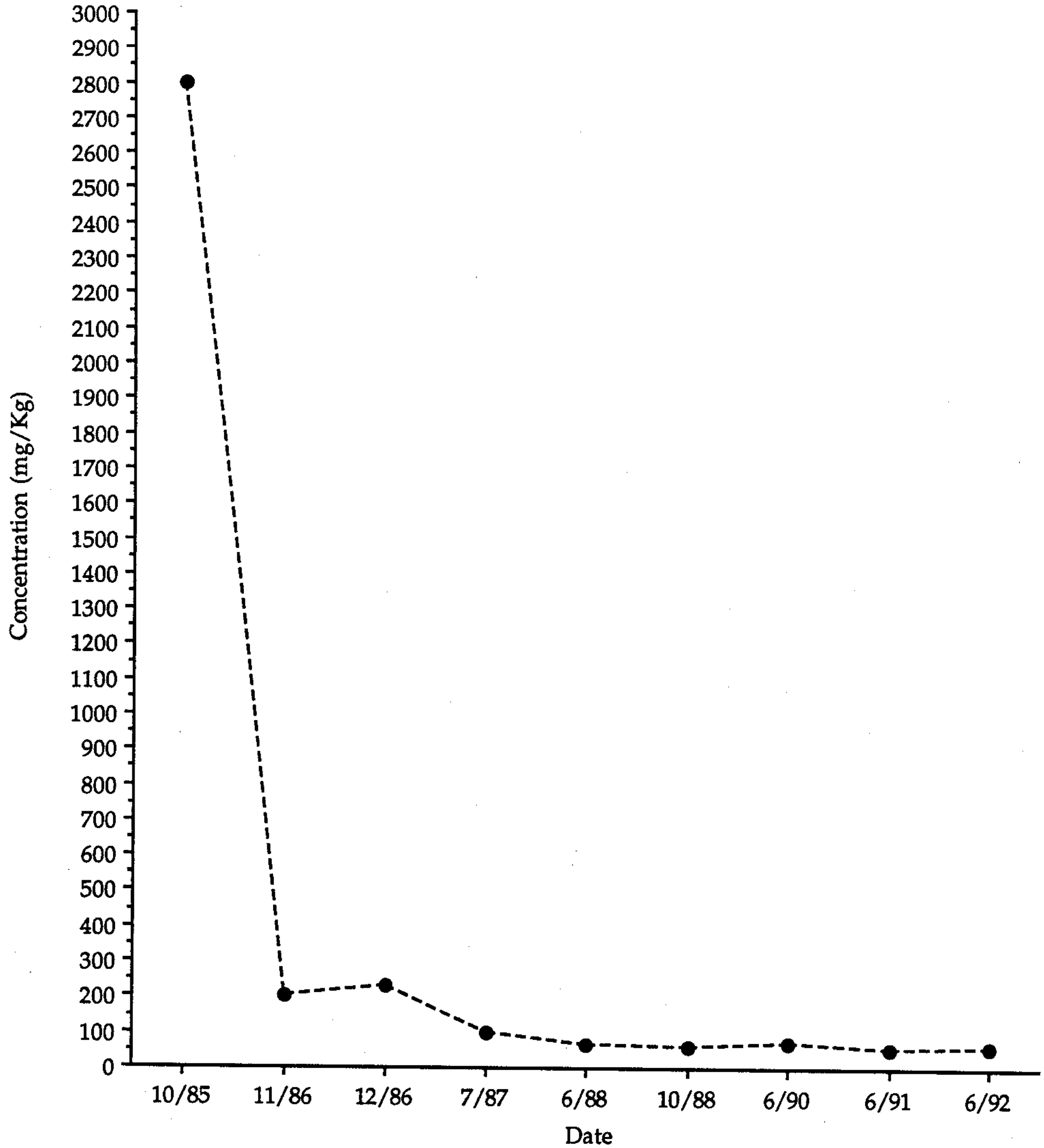


Figure 20. Grass boron concentrations within 50 meters (164 feet) of the Bottle Rock muffler.

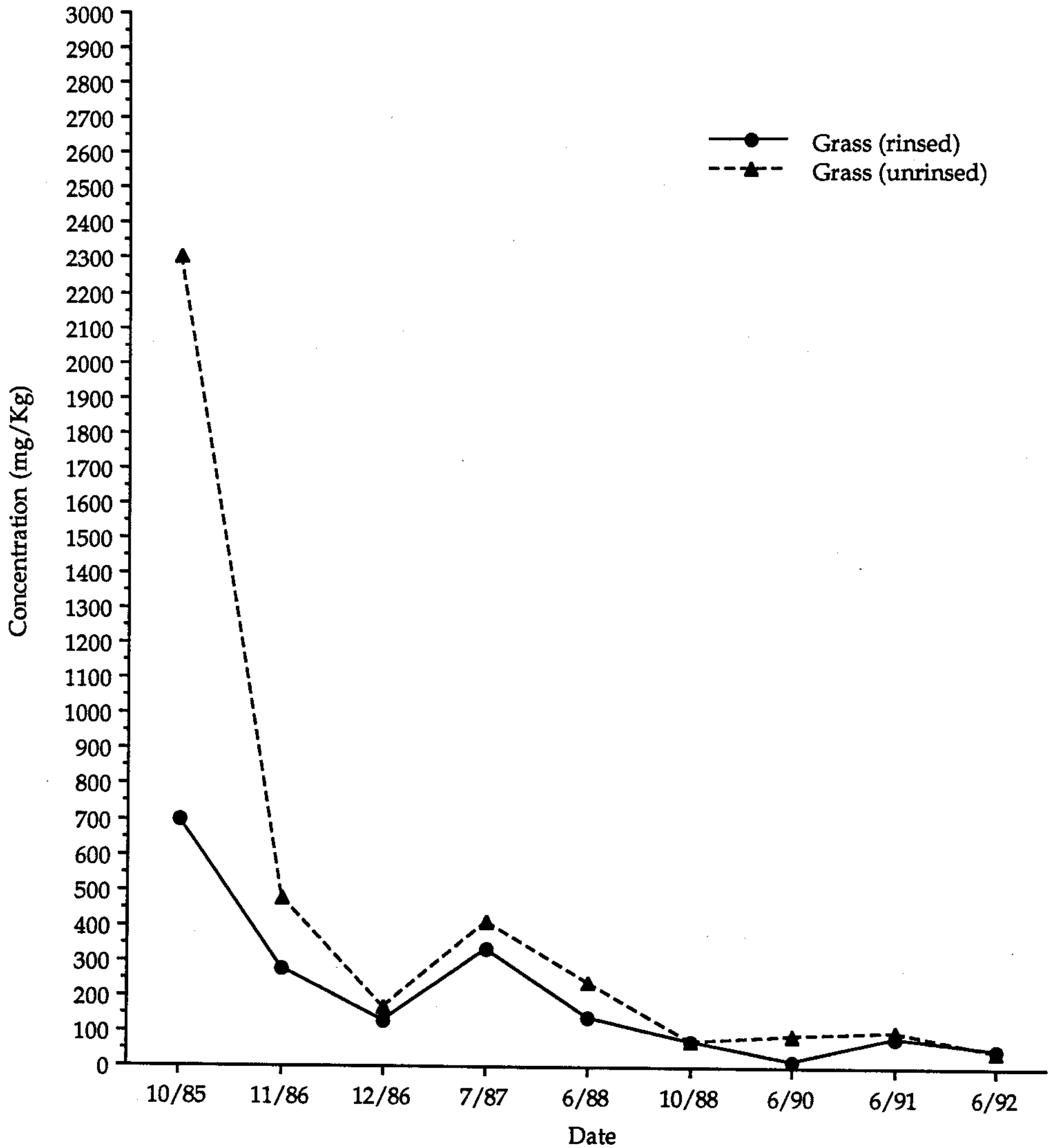


Figure 21. Douglas fir boron concentrations collected within 50 meters (164 feet) of the Bottle Rock muffler.

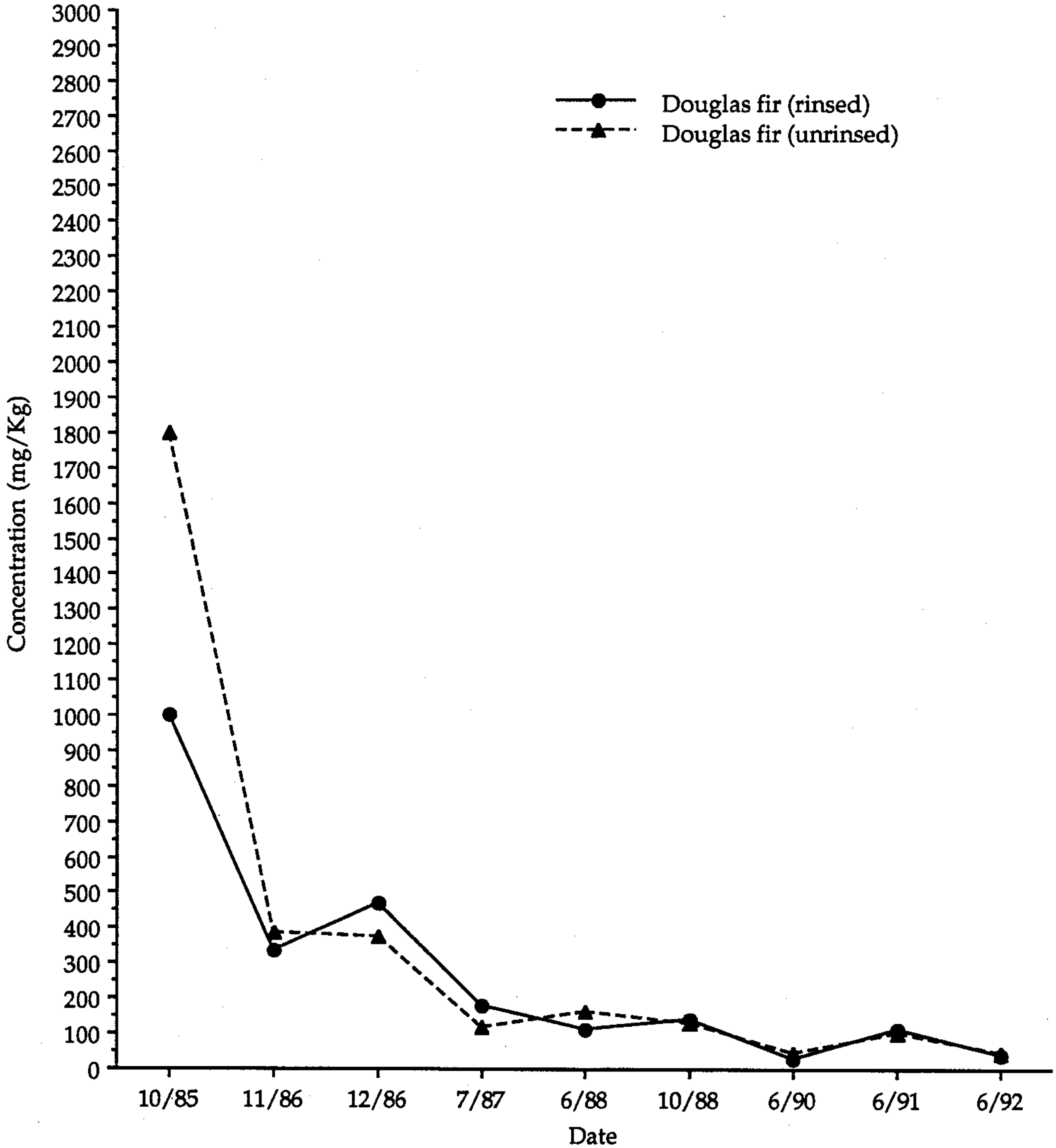


Figure 22. Madrone boron concentrations collected within 50 meters (164 feet) of the Bottle Rock muffler.

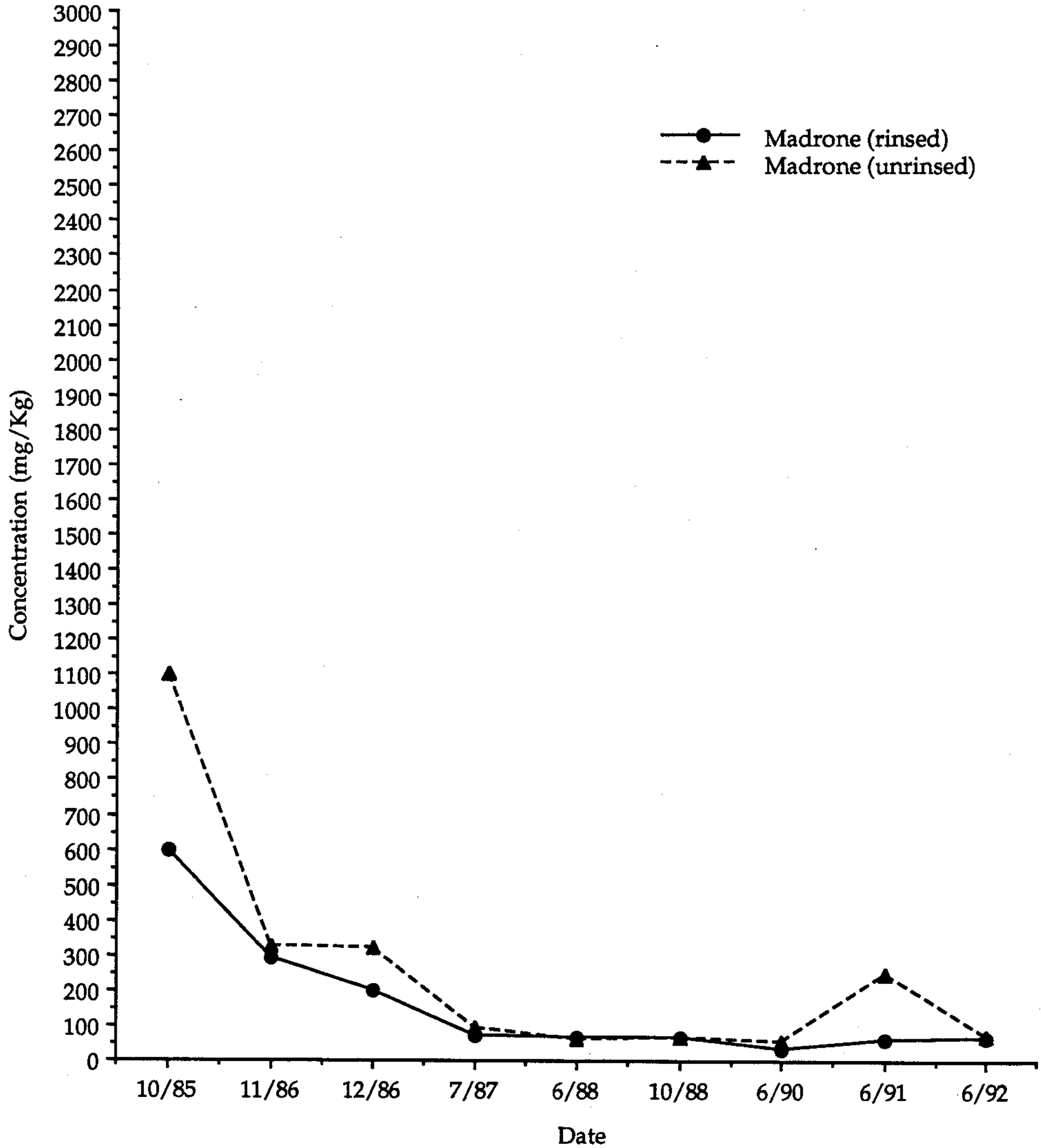
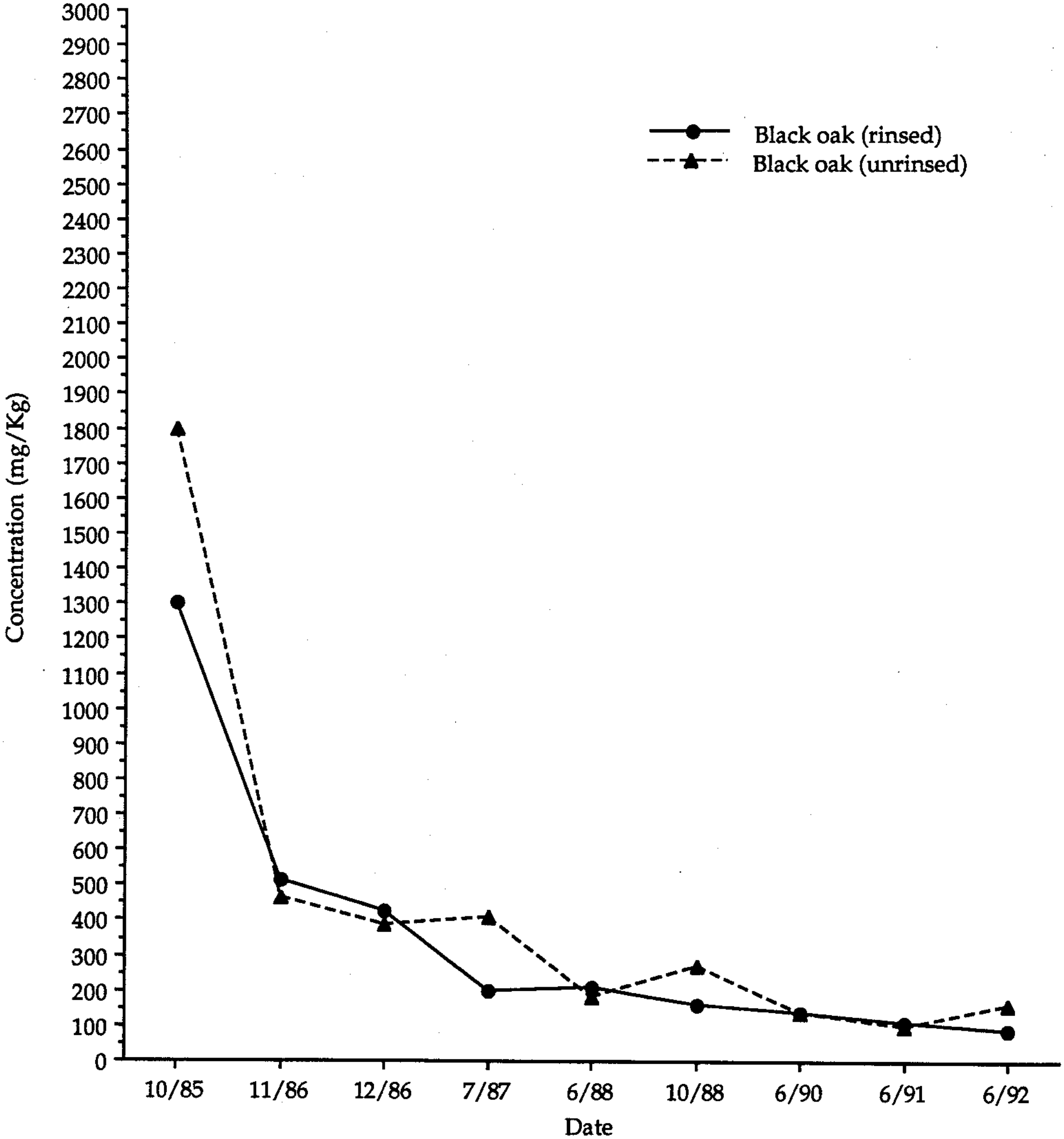


Figure 23. Black oak boron concentrations collected within 50 meters (164 feet) of the Bottle Rock muffler.



ASSESSMENT

During the initial steam stacking incident in 1985, phytotoxic concentrations of boron and sodium were deposited on soils and vegetation around the Bottle Rock muffler. Severe vegetative damage was apparent on vegetation directly exposed to the geothermal drift within 60 days of the initial steam stacking incident. Vegetation damaged, but not killed, in 1985 rapidly recovered in subsequent years during power plant operation.

Leaf surface area loss data, analysis of aerial false color infra-red photography, and soil and leaf tissue chemical concentrations generally indicate vegetative recovery and reduced contaminant levels during power plant operation following the initial steam stacking incident. This trend toward vegetative recovery generally continued following elimination of geothermal emissions.

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